

***Assessment of and Information on Unexploded Explosive
Ordnance Treatment Methods and Technologies and
Recommendations for Implementation***

Compiled and Assessed by Ryan Ginsburg

Summary of the Issue at Hand

Upon preliminary examination of the problem of what to do with unexploded ordnances, it becomes clear that one must take into account the many different types of ordnances and the various chemicals that comprise those types. In addition to the wide array of items in need of treatment, there is also a massive variance in scale, from the few sporadically confiscated items that the local sheriff's department in a rural or low-income area have to manage, to the ever-growing stock piles in the possession of federal agencies and the military that together equal many thousands of tons. Due to the nature of the problem, certain technologies or combinations of technologies are more or less effective than others given the conditions specific to the situation and must be evaluated to a certain extent on a case by case basis. For instance, this could mean that despite the fact that a certain technology and/or method may be proven destructive and/or to have lasting effects that are detrimental to the environment, it may be the most appropriate in emergencies. It is especially important to take recognize the speed at which some of technologies develop and to leave room for and even encourage their growth and implementation.

Types of Energetic Materials

Military Munitions

- As defined by the United States Department of Defense:
 - Military Munitions
 - “Military munitions means all ammunition products and components produced for or used by the armed forces for national defense and security, including ammunition products or components under the control of the Department of Defense, the U.S. Coast Guard, the U.S. Department of Energy, and the National Guard. The term includes confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot controagents, smokes, and incendiaries, including bulk explosives, and chemical warfare agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components of the above.”

Fireworks

- As defined by the American Pyrotechnics Association:
 - Consumer Fireworks
 - “Also known as 1.4G fireworks. Fireworks that are intended for use by the consumer. The permitted usage of consumer fireworks varies by state. Examples are fountains, cones, and firecrackers.”
 - Display Fireworks

- “Large fireworks articles designed to produce visible or audible effects for entertainment purposes by combustion, deflagration, or detonation.”

Marine, Roadside, and Signal Flares

- As defined by the National Fire Protection Association:
 - All Flares
 - “A pyrotechnic device designed to produce a single source of intense light for a defined period of time.”

Auto Air Bag Explosives

Model Rocket Propellant

- As defined by the National Fire Protection Association:
 - Model Rocket Motor
 - “A solid propellant rocket motor that has a total impulse of no greater than 160 N-sec (36 lb-sec), an average thrust of no greater than 80 N (18 lbf), and that otherwise meets the other requirements set forth in NFPA 1125, Code for the Manufacture of Model Rocket and High Power Rocket Motors.”

Bulk Possession of Energetic Materials

Energetic materials are in the possession of various arms of the federal government and corners of private industry. Some energetic materials are in the possession of these groups to the end of conducting general business (ex. the military requires energetic materials to carry out their defined purpose) while some are confiscated due to a breach in the regulatory framework surrounding a particular type of energetic item, and still others are possessed for the purpose of either reintroducing, repurposing, recycling, or demilitarizing.

- Department of the Army
- Department of Energy
- Nation Aeronautics and Space Administration
- National Park Service
- Law Enforcement
- Construction, Demolition, Mining, and Pyrotechnic Industries

Compilation of Technologies

The list below is a compilation of information on many techniques and technologies used to dismantle, desensitize, and/or reuse explosive materials and some of the public and private institutions that have or are currently developing them. To promote conceptual understanding of the items on the list, they are categorized as either chemical, physical, or biological processes.

Physical

- Fluid-jet Cutting
 - Description
 - Water is pressurized and directed through a narrow nozzle at a velocity high enough to accurately cut through material; if the material is especially hard or thick, an abrasive is added for extra cutting power. As the fluid blade cuts the explosive material, the reactive material is flushed out and soaked to the point of desensitization
 - Developers/Testers*
 - JetEdge Inc.
 - Gradient Technologies
 - Flow International Inc.
 - Goldtec
 - Team Technologies
 - Saviour Diagnostics (Kejo Limited Company)
 - IEOD Engineering ltd.

*There is a group called the Waterjet Technology Association and Industrial & Municipal Cleaning Association that could serve to help identify more developers of this technology

- Studies, Papers, or Reports
 - [HYPERLINK
"http://jetedge.com/content.cfm?fuseaction=dsp_success_case&case_ID=110"
]
 - [HYPERLINK
"http://www.dtic.mil/ndia/2007global_demil/SessionIIIB/1620Summers.pdf"]
 - [HYPERLINK
"http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.40.886"]
 - [HYPERLINK "http://www.nap.edu/openbook.php?record_id=9660&page=235"
]
 - [HYPERLINK
"http://www.dtic.mil/ndia/2007global_demil/SessionIIB/1435Miller.pdf"]
 - [HYPERLINK "http://www.osti.gov/scitech/servlets/purl/80976"]
 - [HYPERLINK
"http://www.dtic.mil/ndia/2007global_demil/SessionIIIB/1555Ochs.pdf"]
 - [HYPERLINK
"http://www.kmtwaterjet.com/FF%20Journal%20KMT%20Waterjet%20Cutting_
Gradient%20Technology.pdf"]
 - *Using Waterjet in Reverse Logistic Operations in Discarded Munitions Processing*

- Sergej Hloch, Hakan Tozan, Mustafa Yagimli, Jan Valíček, Krzysztof Rokosz
 -
- Vacuum infusion
 - Description
 - The air or liquid is vacuumed out from the mixture and then rapidly introducing liquid that will be forced to diffuse into the air pockets and desensitize the explosive material
 - Developers/Testers
 - Department of Transportation
 - Studies, Papers, or Reports
 - *What in the World to do with Waste Fireworks Articles*
 - Dr. Spencer Watson, US DOT/PHMSA
- Ultrasonic Bath Soaking/Disassembly
 - Description
 - Only exists in theory; too many unknown to properly assess
 - Studies, Papers, or Reports
 - [[HYPERLINK "http://www.google.com/patents/US7449072"](http://www.google.com/patents/US7449072)]
- Injection Soaking
 - Multiple barbed needles are pressed into casing and desensitization fluid is injected. Problems with alignment, missing needle components, friction sensitive materials, and probable mess.
 - Too many unknowns to properly assess
 - Studies, Papers, or Reports
 - None available
- Cryogenic Treatment
 - It has shown that lowering the temperature of explosive materials does not have a significant effect on the reactivity level of the explosive material
 - Studies, Papers, or Reports
 - [[HYPERLINK "http://www.dtic.mil/dtic/tr/fulltext/u2/908452.pdf"](http://www.dtic.mil/dtic/tr/fulltext/u2/908452.pdf)]
 - [[HYPERLINK "https://www.google.com/webhp?sourceid=chrome-instant&rlz=1C1CHFX_enUS590US591&ion=1&espv=2&ie=UTF-8"](https://www.google.com/webhp?sourceid=chrome-instant&rlz=1C1CHFX_enUS590US591&ion=1&espv=2&ie=UTF-8) \ "q=cryogenic+explosives+disposal"]

Chemical

- Detonation chambers/thermal treatments
 - Description

- Explosive materials are either detonated or exposed to high heat while inside a blast proof chamber
- Advantages
 - Technology developed, available, and in use
 - High degree of certainty for desensitization
 - Likely that finished material could be shipped to be treated
 - Also available in mobile form
- Disadvantages
 - **Need for extreme caution**
 - **High public opposition**
 - **Further remediation required for finished product**
 - **Unlikely that any material will be reused**
- Developers/Testers
 - Sandia National Laboratories
 - CH2M Hill
 - International Explosive Ordnance Disposal ltd.
 - PLANTECO
 - NABCO
 - Heritage Disposal and Storage
 - Dynasafe
 - El Dorado Engineering
 - International Environmental Services (IES)
 - Clean Harbors
- Studies, Papers, or Reports
 - *Anniston Chemical Agent Disposal Facility Preliminary Static Detonation Chamber Emissions Test Report*
 - URS Anniston, Chemical Materials Agency, Alabama DEM
 - *Mobile Explosion Containment Vessel*
 - Dynasafe
 - *ASTSWMO Presentation, Explosive Destruction System*
 - Utah Division of Solid and Hazardous Waste
 - [[HYPERLINK "https://share.sandia.gov/news/resources/releases/2005/def-nonprolif-sec/bio-EDS.html"](https://share.sandia.gov/news/resources/releases/2005/def-nonprolif-sec/bio-EDS.html)]
- Open burning/ open detonation
- Description
 - In a remote field or firing range, one places energetic ordnances in either a ditch, submerged underground pit, directly on the surface, or on a concrete slab and initiates combustion by means of an accelerant or directed charges.

- Advantages
 - Simple and fast way to get rid of a large amount of energetic materials
 - Low initial investment
 - Very high positive desensitization rate
- Disadvantages
 - Potential severe environmental impact (possible creation of a Superfund site)
 - Further treatment such as soil remediation likely to be necessary
 - Potential violation of EPA regulations
 - Unlikely that materials will be reused (except for some metal scrap)
- Studies, Papers, or Reports
 - [[HYPERLINK](http://www.sciencedirect.com/science/article/pii/S0304389401003582) "http://www.sciencedirect.com/science/article/pii/S0304389401003582"]
 - [[HYPERLINK](http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA556181) "http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA556181"]
 - *Open Burning and Open Detonation Questions and Answers*
- Acid digestion
 - Description
 - Use of acid digestion to erode energetics casing exposing the internal energetics for further remediation.
 - Advantages
 - Can desensitize the whole explosive
 - Eliminates need for dismantling whole explosives if they are very old, corroded, or damaged in any way
 - Can be mounted on mobile platform
 - Disadvantages
 - Potential for partial/incomplete desensitization
 - End product requires further treatment
 - Difficulties scaling up
 - No testing on fireworks, flares, or airbags
 - Developers/Testers
 - Battelle Memorial Institute
 - Ricardo-AEA
 - Studies, Papers, or Reports
 - *Review of International Technologies for Destruction of Recovered Chemical Warfare Material*
 - *Review and Evaluation of Alternative Technologies for Demilitarization of Assembled Chemical Weapons*
 - *“Assessment of Explosive Destruction Technologies for Specific Munitions...”*

- Chemical Reduction using Activated Hydrosulfide
 - Description
 - Use of sulphur based bulk reductants to quickly desensitize energetic material that has been removed from its protective cover/casing.
 - Advantages
 - No residuals processing other than separation of water
 - Disadvantages
 - Requires dumping of formate and acetate into environment
 - Should be metabolized by bacteria but it is not clear what the overall effect of this would be
 - Developers/ Testers
 - MuniRem (formerly PLANTECO)
 - Studies, Papers, or Reports
 - *Investigation and Assessment of Residual Explosives- Explosive Hazard Remedial Action*
 - CH2M Hill
 - *Planteco Process Design 02/24/13*
 - Planteco
 - *Bench Scale Tests for the Demonstration/ Validation of MuniRem's Efficacy for Instant Neutralization and Destruction of Lead Styphnate and Trinitroresorcinol*
 - Dr. Valentine Nzengung; MuniRem Environmental, LLC
 - *Demonstration/ Validation of Rapid Chemical Degredation of Reclaimed and Stockpiled Explosive D (Picric Acid-Based Explosives) by MuniRem at Gradient Technology Facility, Elk River, MN*
 - Planteco Environmental Consultants, LLC
 - *Protocol for Nitrocellulose Propellant Destruction Kit (PDK)*
 - Planteco, Inc
 - *Use of MuniRem to Instantly Neutralize Energetics and Manage Explosive Risks*
 - Valentine Nzengung; Planteco Environmental Consultants, LLC
 - [[HYPERLINK "http://www.google.com/patents/US20140206922"](http://www.google.com/patents/US20140206922)]
 - [[HYPERLINK "http://news.uga.edu/releases/print/uga-invention-neutralizes-human-and-environmental-threats-from-explosives-c/"](http://news.uga.edu/releases/print/uga-invention-neutralizes-human-and-environmental-threats-from-explosives-c/)]
- Supercritical water oxidation
 - Advantages
 - Potentially effective
 - Existing technology for remediation of other wastes
 - Disadvantages
 - Very expensive, pure titanium vessel

- Developers/Testers
 - General Atomics
 - Sandia National Laboratory
- Studies, Papers, or Reports
 - <http://www.ga.com/supercritical-water-oxidation>
- Molten salt oxidation
 - Type of nuclear fission that could use the EM as fuel
 - **Means that there would be nuclear waste**
 - Developers/Testers
 - Lawrence Livermore National Laboratories
 - Studies, Papers, or Reports
 - [HYPERLINK "http://link.springer.com/chapter/10.1007/978-1-4613-0405-0_29" \l "page-2"]
 - [HYPERLINK "<http://www.google.com/patents/US5434335>"]
- Electrokinetic remediation and “Bioelectrokinetic” remediation
 - Used mostly for explosive contaminated soil
 - Developers/Testers
 - Electrokinetics Inc.
 - Geokinetics International Inc.
 - Electro-Petroleum Inc.
 - Studies, Papers, or Reports
 - [HYPERLINK "<http://www.sciencedirect.com/science/article/pii/S0013468612005981>"]
- Reverse osmosis filtration
 - Generally used for waste water remediation
 - Developers/Testers
 - Evoqua Water Technologies
 - Degremont Technologies
 - Studies, Papers, or Reports
 - [HYPERLINK "<http://www.roconn.com/article12.htm>"]
- Nanomaterial
 - Description
 - Process that uses a reagent to breakdown and desensitize explosive materials by combining reagent with various catalysts such as vitamin C and some metals
 - Advantages
 - Cheap
 - Reagent is inexpensive
 - Catalysts vary in price but are relative inexpensive

- Potentially available for all levels of EOD
 - Very long shelf life and minimal shipping limitations
- Safe
 - Prevents human contact and need for dismantling
- Simple
 - As easy as placing chemicals in a plastic drum, mixing water, adding explosives/catalysts, placing cover, and waiting ≤ 24 hours
- Efficient
 - End product can be used to make epoxy resins
 - Principal reagent can be used in one process for multiple batches
- Disadvantages
 - Potential for partial/incomplete desensitization
 - No testing on whole fireworks, flares, or airbags though basic components have been tested
 - No existing mechanized or mobile unit though plans do exist
- Studies, Papers, or Reports
 - *MIPT Final Report; In-Situ Incapacitation of Explosives*
 - National Memorial Institute for the Prevention of Terrorism
 - *Development of Chemical Systems for the Demilitarization of Unexploded Ordnance in the Field*
 - Dr. Allen Apblett and Nicholas Materer
- Conversion to fertilizer (alkaline or base hydrolysis with humic acid)
 - Base hydrolysis has been proven to desensitize explosive materials; this combined with humic acid produces an effective slow release fertilizer for agricultural use
- Developers/Testers
 - ArcTech (ActoDemil)
- Studies, Papers, or Reports
 - *Review of Energetics, Explosives, Pyrotechnics, Chemical and Munition Devices and Various Demilitarization Techniques*
 - ArcTech, Inc
 - *Pilot-Scale Hydrolysis Processing of HMX-Based Plastic-Bonded Explosives*
 - Los Alamos National Laboratory
 - *UXBase: Non-thermal Destruction of Propellant and Explosive Residues on Ordnance and Explosive Scrap*
 - UXB International, Inc.
 - *Alkaline Hydrolysis of the Cyclic Nitramine Explosives RDX, HMX, and CL-20: New Insights into Degradation Pathways Obtained by the observation of Novel Intermediates*
 - Biotechnology Research Institute

Biological

- Bioremediation (Composting)
 - Developers/Testers
 - PLANTECO
 - Oirca
 - Studies, Papers, or Reports
 - [[HYPERLINK "http://www.google.com/patents/US20060030025"](http://www.google.com/patents/US20060030025)]
 - [[HYPERLINK "http://compost.css.cornell.edu/tnt.html"](http://compost.css.cornell.edu/tnt.html)]
 - [[HYPERLINK "https://www.llnl.gov/str/Knezo.html"](https://www.llnl.gov/str/Knezo.html)]
- Phytoremediation
 - Developed by PLANTECO for soil remediation

Assessing and Choosing from Identified Technologies

In assembling and assessing the list above, five questions were kept in mind to narrow the area of focus, though the first question is not addressed in this paper. Those five questions are as follows:

1. Can we produce more environmentally friendly explosive materials?
2. Can we reuse/recycling any part of the explosive?
3. How can we dismantle explosives?*
4. How can we permanently desensitize explosives?*
5. How can we end the process with as close to zero waste as possible?*

* refers to safely → effectively → efficiently → cheaply → quickly

From the list above that contains all of the techniques and technologies that have been identified and on which a reasonable amount of information was ascertained, a smaller, more detailed list was created; the following are technologies that have shown promise for energetic material treatment. These technologies either physically alter the explosive materials and/or temporarily desensitize energetics to the point where they could potentially or chemically alter the energetic materials permanently undermine their reactive properties and are organized as such. Some of these technologies can be combined to maximize effectiveness. Also, the finished products of these processes have varying levels of value and/or usability. The criteria used to evaluate the efficacy of these technologies, in order of importance are as follows:

- I. Safety
- II. Security
- III. Environmental compatibility (including residuals, materials used, and reusability)
- IV. Compliance with federal laws and policies
- V. Cost (including throughput and efficiency)

Physical Alteration

Fluid-jet cutter

1. Uses a very high pressure stream of fluid to dismantle and flush-out explosives without detonation
 - a. Fluid could include an abrasive for cutting through metal
 - b. Fluid could also be a desensitizing agent such as ActoDemil, MuniRem, or XploSafe
2. Result is a slurry of explosive material and maybe powdered metal that are not reactive as long as they are wet
3. Slurry could either be treated or potentially shipped to treatment facility
 - a. ActoDemil, MuniRem, and XploSafe could also be used to treat at this stage
- Throughput
 - Medium-High
- Cost
 - Variable; from low to high
- Residual
 - Slurry of explosive material, cutting agent, and maybe powdered metals and abrasive
- Derivation of Effectiveness
 - Safely and quickly dismantles explosive ordnances
- Applications/testing
 - Extremely high pressure/flammability conditions
 - Blasting Caps
 - Perchlorate, TNT, Teteryl, Picric Acid, ect.
 - No testing done on whole fireworks
- Safety
 - Removes human contact
 - Ability to treat without removing ordnances from cases
- Advantages
 - Fully mechanized/robotic
 - Extensively tested
 - Also available in mobile form
- Disadvantages
 - Potential for water to react with powdered metals

Vacuum infusion

1. Submerge items in high boiling inert liquid
2. De-air with high vacuum for 1-5 minutes
3. Release vacuum and allow liquid to infuse to space where air was

OR

1. Place item in vacuum chamber

2. Remove air
 3. Infuse with liquid
- Advantages
 - Technology used to marinate meat; is available, simple, and inexpensive
 - Potential for swapping of fluid for various desensitizing fluids (ActoDemil, MuniRem, XploSafe)
 - Most units are small enough to carry and do not require elaborate transport
 - Disadvantages
 - Does not work for military munitions (cannot permeate metal casings)
 - Potential for partially desensitized material (improper infusion)
 - No scaled-up/mobile unit
 - DOT stopped R&D for years (recently refunded)
 - Throughput
 - a. Undetermined
 - Cost
 - a. Low-cost for small scale due to availability of technology in other industries
 - b. Large scale costs are undetermined
 - Residual
 - a. Slurry of explosive materials and possibly some fluid used for process
 - Derivation of Effectiveness
 - a. Could be very useful for fireworks
 - i. Possible means of desensitizing explosive material pre-dismantling
 - ii. Possible reuse/recycle of relatively undamaged materials
 - Applications/testing
 - a. Very little testing
 - Safety
 - a. No direct human contact required though there seems to be a chance of partial or incomplete desensitization

Improved Conventional Munition (ICM) R³

1. Disassemble using milling techniques or underwater band saw
 2. Shrink wrap munition item to prevent disturbance
 3. Remove copper core
 4. Remove explosives including A5 explosive
- Throughput
 - a. Relatively high though human labor required which impedes mechanization
 - Cost

- a. $(\text{Cost of disassembly}) - (\text{Sale Price of Salvaged Materials}) = \text{Total Cost}$
- Residual
 - a. Close to nothing; most if not all parts are salvaged
- Derivation of Effectiveness
 - a. Good record for disassembly without reaction
 - b. Very little waste/environmental impact
 - c. Maximizes reuse of materials
- Applications/testing
 - a. Only used for Improved Conventional Munitions
- Safety
 - a. Concerns about amount of handling by human hands that the explosive materials undergo
 - b. Thermal event has not taken place but is likely given numbers
- Advantages
 - a. Very little waste/environmental impact
 - b. Maximizes reuse
- Disadvantages
 - a. Does not work for other types of explosives
 - b. Could be more automated to reduce human contact
 - i. This would likely also increase throughput

Chemical Alteration

Open burning/ Open Detonation (OB/OD)

1. Place energetic materials near together (maybe on a concrete pad) in a remote area
 2. Apply accelerant or equivalent
 3. Stand a considerable distance away and initiate **burn**
 4. Take care to prevent against harm from kick out
- OR**
1. Dig a pit in a remote area
 2. Place energetic materials near together in the pit
 3. Cover pit with dirt
 4. Fit explosives with fuse, detonator, or equivalent combustion initiator
 5. Stand a considerable distance away and initiate **detonation**
- Throughput
 - a. No definite limit
 - Cost
 - a. Difficult to determine
 - i. $(\text{Cost to Carry Out OB/OD}) + (\text{Cost of Site Remediation}) = \text{Total Cost}$

1. Cost to carry out OB/OD is relatively low
 2. Cost to remediate site is very high (often becomes a Superfund site)
- Residual
 - a. Considerable discharge of debris and explosive material both into air and soil
 - b. It is thought that in the case of complete combustion, there is considerably less contamination
 - i. Degree as well mobility of contamination per unit of explosive is not clear due to inadequate soil and especially air monitoring techniques
 - Derivation of Effectiveness
 - a. Cheap, fast, easy, obvious
 - Applications/testing
 - a. Has been extensively used on a wide variety of explosive materials
 - Safety
 - a. Relatively safe for those directly involved though there is concern about the contamination that it causes
 - Advantages
 - Easy
 - Simple
 - Effective for demilitarization
 - High total demilitarization rate
 - Disadvantages
 - Long term environmental impacts and contamination
 - Very costly after initial burn or detonation
 - No potential for reuse of materials

Detonation chambers/thermal treatments

1. Place items in blast safe chamber
 2. Initiate detonation via shock, heat, ect.
 3. Result is non-reactive ash material that may need to be treated further
- Advantages
 - Technology developed, available, and in use
 - High degree of certainty for desensitization
 - Likely that finished material could be shipped to be treated
 - Also in tested in mobile form
 - Disadvantages
 - **Need for extreme caution**
 - **High public opposition**
 - **Further remediation required for finished product**

- **Unlikely that any material will be reused**
- **Limited throughput (capacity and cleaning between detonations)**

Nanomaterial

1. Place explosives in vessel with reagent (nanomaterial)
 2. Then add catalyst (could be vitamin C or various types of metals including those used to construct munitions casings) and mix
 - a. A change in color from blue to yellow will indicate neutralization start
 3. Let mixture sit for a maximum of 24 hours and
 4. Result is non-toxic mixture of metals, reduced explosives and hydrogen
- Throughput
 - Difficult to determine as no unit has been developed but it is likely to be quite high if mechanized, combined with fluidjet cutting, or if there was a very large area to work in such as a permanent processing facility
 - Cost
 - Difficult to determine
 - i. Reagent is inexpensive and can often be reused
 - ii. Catalysts vary in price but are relative inexpensive and is not necessary if metal is already present
 - iii. Potentially available for all levels of EOD
 - iv. Very long shelf life and minimal shipping limitations
 - $(\text{Cost of process}) - (\text{Sale price of recycling material}) = \text{total cost}$
 - Residual
 - Varies by type of explosive material
 - i. Some nonhazardous combination of water, potassium chloride, and sometimes metals and metal oxides
 - Components of end product can be used to make epoxy resins or fertilizer additive
 - i. Presumably everything can be recycled
 - Derivation of Effectiveness
 - Can desensitize explosive hazard and convert it into value added material that can be made into epoxy resins or potassium based fertilizer additive and sold
 - Usable by different levels of EOD
 - i. As easy as placing chemicals in a plastic drum, mixing water, adding explosives/catalysts, placing cover, and waiting ≤ 24 hours
 - Can use metals as catalyst for reaction making military munitions an obvious application
 - Applications/testing
 - Testing on TNT, black powder, PETN, RDX, HMX, azides (airbags), model rocket cartridges and perchlorate based energetic materials
 - Successfully able to breakdown and desensitize a whole AK47 bullet

- Safety
 - No thermal events or reactions to date
 - Removes requirement of direct handling by humans
- Advantages
 - Cheap
 - Safe
 - Simple to use
 - Efficient
- Disadvantages
 - Potential for partial/incomplete desensitization
 - No testing on whole fireworks, flares, or airbags though testing on basic components has shown positive results
 - No existing mechanized or mobile unit though plans do exist

Chemical Reduction using Activated Hydrosulfide

1. Place sulphur based bulk reductants (powder form), water, and separated energetic material (removed from casing) in a container
 2. Let mixture sit for 20-60 minutes
 3. Result is nonreactive/nonhazardous slurry of formate, acetate, nitrogen gas, and sometimes nitrites
 4. Filter end product through reactive columns to reuse “waste”-water
- Throughput
 - a. 200 lbs/hour (if theoretical mechanized unit is produced)
 - Cost
 - a. \$68-98/20,000 tons
 - Residual
 - a. Formate, acetate, nitrogen gas, and sometimes trace amounts of nitrites
 - i. Formate and acetate are metabolized by bacteria in ecosystems
 - ii. Nitrogen gas is released into the atmosphere
 - iii.
 - Derivation of Effectiveness
 - a. Fast and effective desensitization of energetic material
 - Applications/testing
 - a. Has been tested and proven effective on a wide variety of major explosive materials
 - Safety
 - a. Has been combined with automated fluidjet cutting technology
 - i. Minimizes direct handling by humans and increases throughput
 - Advantages

- High throughput
- Low cost
- Little or no post-process remediation
 - “waste”-water can be reused
- Disadvantages
 - Potential for partial/incomplete desensitization as with all chemical treatments
 - No mechanized unit available though one has been developed
 - Requires release of formate and acetate into environment
 - Both are carbon sources and should be quickly metabolized by bacteria but large scale effect is unknown

Conversion to fertilizer (alkaline or base hydrolysis)

5. Place energetic materials in a hopper that feeds into the ActoDemil Unit
6. Unit combines energetic material with potassium hydroxide (sometimes also humic acid)
 - a. Reductive Hydrolysis with humic acid results in humic acid absorbing nitrogen, organic components, and other compounds
7. Results in a desensitized solution
 - a. With fertilizer → contains organic humic acid and mineral nutrients
 1. The presence of humic acid enables a consolidation of all materials
 2. Any heavy metals that are present in the end product can be separated with an acid
- Throughput
 - a. 1 ton/10 hours
- Cost
 - a. $(\text{Cost of conversion process}) - (\text{Sale price of Fertilizer End Product}) = \text{Total Cost}$
- Residual
 - a. Humic acid combined with formerly explosive material which serves as a proven and effective fertilizer
- Derivation of Effectiveness
 - a. Converts explosive hazard into value added fertilizer product
 - b. Can be combined with fluidjet cutting technology
- Applications/testing
 - a. Has been tested and proven effective on a wide variety of major explosive materials
 - i. No major explosive materials have yielded negative desensitization result
- Safety
 - a. Can be combined with automated fluidjet cutting technology
 - i. Minimizes direct handling by humans
- Advantages
 - Fertilizer is slow release (limits surplus from leaching into waterways)
 - Resulting fertilizer can be sold which reduces overall cost and increases efficiency

- No further remediation necessary
- Could be combined with other technologies such as fluidjet cutting, vacuum infusion, or injection soaking
- Different sized mobile treatment units are available
- Disadvantages
 - Potential for partial/incomplete desensitization

Bioremediation (Composting)

1. Start with slurry of energetic material and either water or soil
 2. Add bulking agents and biodegradable material as well as nitrogen and carbon sources
 3. Adjust moisture, temperature, oxygen, and the carbon-nitrogen ratio to the appropriate levels to achieve degradation of contaminants
- Throughput
 - a. Slow but could easily be scaled up to speed
 - Cost
 - a. Difficult to determine → $(\text{Cost to Compost}) - (\text{Sale Price of Compost}) = \text{Total Cost}$
 - Residual
 - a. Compost
 - Derivation of Effectiveness
 - a. Yields a non-hazardous product that can be sold or reintroduced into natural setting
 - Applications/testing
 - a. Testing has been done on many types of explosives though most has been done on
 - Safety
 - a. Renders the explosive slurry non-hazardous
 - Advantages
 - End product is very innocuous with no shipping, handling or disposal requirements
 - Mobile units have been developed and are in use
 - Disadvantages
 - The process can be slow
 - Considerable pretreatment is necessary

Summary Table for Choosing from Identified Technologies

Technology	Residuals	Throughput (relative and estimated)	Cost (Relative)	Testing	Advantages	Disadvantages	Unit Type
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Fluidjet Cutting	Casing plus energetic slurry	Medium to high	Med.	Extensive testing; many types and volumes	Dismantles and desensitizes	Potential reaction of H ₂ O w/ powdered metals	Mobile and stationary
Vacuum Infusion	Energetic material plus infusion fluid	Medium	Low	Small testing, discount.; recently restarted	High availability, low cost, good for fireworks	Limited testing and no large scale developed	No unit has been designed for this purpose
Detonation Chambers	Starting material w/o reactivity	Medium-high to high	Med. to high	Extensive testing; many types and volumes	High desens. rate, availability, throughput	Unpredictable	Mobile and stationary
ICM R³	No residuals	Medium-high to high	Low	Extensive use for ICM	Complete salvage and resale	Only works for one type (ICM)	Stationary
Conversion to Fertilizer (hydrolysis)	Humic acid and non-reactive energetic compon.	Medium to high	Low to Med.	Extensive testing; many types	Conversion to valuable and effective product	Limited testing on non-munition or	Mobile and stationary
Nanotech.	Depends on explosive material	Not determined; likely high if combined with fluidjet	Low to Med.	Small scale and whole explosives	Conversion to product, very simple and safe	Limited testing at large scale and no unit developed	No unit available
Chemical Reduction w/ activated hydrosulfide	Formate and acetate can be released in envi. And eaten by bacteria	Low to high	Low-Med.	Testing and use done on various types of explosives and in conjunct. w/ fluid cutting	Quickly, cheaply desensitizes energetic materials removed from/or their casings	Req. dumping of formate and acetate, trace amount of nitrites indicative of partial desens. and no mechanized unit	Unit in development
Bioremed.	Compost	Low to high	Med. to high	Has been used on explosive material but mostly soil clean-up	Very environment -tally friendly, conversion to product, few residuals	Choice between lower throughput and large processing area	Mobile and stationary

Treatment Units

In addition to choosing the right technology for a given situation, one must also take into consideration the various conditions that affect the treatment unit type that should be employed. Different types of treatment units are best suited for specific circumstances and often cannot be used interchangeably. The two broad categories of treatment units are mobile units and stationary units though within each of these categories, there is a considerable variety.

Mobile Units

The various aspects of mobile treatment units vary considerably. Some of these differing aspects include throughput, portability, and user-friendliness. From units that must be transported on multiple flatbed trucks to hand held or remotely operated devices, mobile treatment units are best suited for emergency situations and on site treatment in limited access locations.

Stationary Units

Among stationary units there is also considerable variation. The two basic types of stationary treatment units are temporary units and permanent units. Stationary units would most commonly be those that facilitate treatments that require large spaces or for continuous waste streams and/or larger quantities.

Conclusions and Recommendations

As previously stated, determining the best technology requires the examination of the characteristics of individual situations. Some of these characteristics might include the degree to which there is a threat to human lives or national security and whether it is imminent, the volume of the problem in need of treatment, the type of explosive material in need of treatment, the level of funding for a project, and the time allotted to solve the problem. The cost of a project is one of the most important factors when referred to as the amount of money that will need to be spent on a given task from when one first is made aware to when no more work is needed; in other words this is the long-term or total cost.

In a situation like this one where alternatives that many would argue are objectively better than those currently in use have existed for years, we must ask ourselves why we have settled for anything less than the latest and greatest. The fact of the matter is that there are those that stand to benefit greatly from the continued utilization of the inferior and outdated. There can be no preference given to anything but the best and the best technology should be the one that is the best for today and for many tomorrows to come.

Points of Contact for Information on Energetics Treatment

Companies

Fluid-jet Cutting:

- Hazardous Devices Program Support Incorporated
 - David Heaven

- (256) 705-3579
 - (256) 656-2283
 - [[HYPERLINK "mailto:david.heaven@hdps-hsv.com"](mailto:david.heaven@hdps-hsv.com)]
- Gradient Technology
 - Paul Miller
 - (763) 792-9990
 - [[HYPERLINK "mailto:info@gradtech.com"](mailto:info@gradtech.com)]
- WARDJet Incorporated
 - (330) 677-9100
 - [[HYPERLINK "mailto:sales@wardjet.com"](mailto:sales@wardjet.com)]
- Jet Edge Incorporated
 - (763) 497-8700
 - [[HYPERLINK "mailto:sales@jetedge.com"](mailto:sales@jetedge.com)]
 - [[HYPERLINK "mailto:service@jetedge.com"](mailto:service@jetedge.com)]
 - [[HYPERLINK "mailto:parts@jetedge.com"](mailto:parts@jetedge.com)]
- Flow International Corporation
 - 253-850-3500
 - [[HYPERLINK "mailto:info@flowcorp.com"](mailto:info@flowcorp.com)]
- Carretta Technology Incorporated
 - Italian based

Other EOD groups and companies:

- Sandia National Laboratories
 - Envi. Mgmt: (505) 282-5200
 - Government relations: [[HYPERLINK "mailto:govrela@sandia.gov"](mailto:govrela@sandia.gov)]
- CH2M HILL/ DEMIL International
 - D. Brint Bixler; Vice President
 - (703) 471-6405 ex. 4600
 - [[HYPERLINK "mailto:bbixler@ch2m.com"](mailto:bbixler@ch2m.com)]
 - Kevin Lombardo; Operations Manager, Munitions Response Program
 - (703) 471-6405 ex. 4180
 - [[HYPERLINK "mailto:klombar2@ch2m.com"](mailto:klombar2@ch2m.com)]
 - Technology: Donovan Blast Chamber
- NABCO
 - Frank Tobin; Chairman and CEP
 - (724) 746-9617
 - [[HYPERLINK "mailto:ftobin@nabcoinc.com"](mailto:ftobin@nabcoinc.com)]
 - Kim W. King, Manager of Engineering and New Product Development
 - (724) 746-9617

- [[HYPERLINK "mailto:kking@nabcoinc.com"](mailto:kking@nabcoinc.com)]
 - Kevin L. Matthews; Vice President, Energy & Environment
 - (202) 349-7010
 - [[HYPERLINK "mailto:kmatthews@nationalstrategies.com"](mailto:kmatthews@nationalstrategies.com)]
 - Oyinade Ogunbekun; Client Services Associate, Energy & Environment
 - (202) 349-7022
 - [[HYPERLINK "mailto:oogunbekun@nationalstrategies.com"](mailto:oogunbekun@nationalstrategies.com)]
 - Tiffany Novotney; Director, Domestic Business Development
 - (724) 746-9617
 - [[HYPERLINK "mailto:tnovotney@nabcoinc.com"](mailto:tnovotney@nabcoinc.com)]
- Planteco International
 - Dr. Valentine Nzungu, founder/CEO
 - (706) 316 3535
 - Jong Lee; Chairman
 - Hong Kong: (852) 3563-9201
 - USA: (213) 985-2600
 - [[HYPERLINK "mailto:jong@plantecointl.com"](mailto:jong@plantecointl.com)]
 - Technology: MuniRem and SAMNAS
- Archtech Incorporated
 - (703) 222-0280
 - Technology: ACTODEMIL
- Heritage Disposal and Storage LLC
 - Mark Vess
 - (308) 389-3155
 - (308) 850-8457
 - mark@heritiage-ds.com
- UXB International Incorporated
 - (540) 443-3746
 - Technology: Dynasafe
- El Dorado Engineering
 - (801) 966-8288
- Applied Research Associates
 - (505) 881-8074
- Reactive Explosives Materials Training Corp (REMTC)
 - (973) 948-0270
 - (800) 736-8295
- International Environmental Services (IES)
 - (909) 928-5671
 - Technology: pyrolytic thermal converter system
- TPL Incorporated

- Hap Stroller; President and CEO
 - (505) 342-4437
 - Main number:
 - (505) 344-6744
 - Technology: conversion to fertilizer (alkaline hydrolysis)
- Sterlinggo
 - (865) 988-6067
- Clean Harbors
 - (800) 444-4244
- Explosive Management Group
 - (902) 222-5097
 - [HYPERLINK "mailto:info@explosivesmanagement.com"]
- Remediation and Natural Attenuation Services Inc.
 - William A. Newman; President
 - (763) 585-6191
 - [HYPERLINK "mailto:bnewman@RNASinc.com"]
- Orica
 - International Phone #: 61 3 9665 7111
 - Technology: Bioremediation of whole explosives
- Battelle Memorial Institute
 - 1 (800) 201-2011
 - Technology: Munitions treatment by acid digestion
 - Bill Schaff
 - (410) 306-8868
 - Marty Hopkins, referred to as technical expert by Mr. Schaff
 - (410) 306-8521
- Ricardo-AEA
 - 44 (0) 1235 75 3000
 - Enquiry@ricardo-aea.com
 - Technology: Acid digestion of metal encased materials
- Liberty Disposal Services Incorporated
 - Todd; President
 - (906) 282-2264
 - [HYPERLINK "mailto:todd@libertydisposalinc.com"]
 - Josh; Operations Supervisor
 - [HYPERLINK "mailto:josh@libertydisposalinc.com"]
 - (906) 221-0934
- Lawrence Livermore National Laboratory
 - **Main Operator:** (925) 422-1100
 - Technology: Molten Salt Oxidation

- U.S. Army Chemical Materials Activity
 - 1-800-488-0648
 - Technology; recovery, storage, treatment, and disposal of chemical weapons
- International Explosive Ordnance Disposal Ltd.
 - 972 (0)3 9015044/5
 - [[HYPERLINK "mailto:info@ieod.co.il"](mailto:info@ieod.co.il)]
- Maxam/EXPAL
 - Based in Spain

People

- Neil C Bruce; Professor of Biotechnology, University of York
 - 01904 328777
- Dr. Allen Apblett; Professor of Chemistry, Oklahoma State University
 - (405) 612-8336 (cell)
 - (405) 744-5943
 - [[HYPERLINK "mailto:apblett@okstate.edu"](mailto:apblett@okstate.edu)]
 - **XPLOSAFE**
 - Technology: XploSens SP and other Xplosafe products
 - Shoaib Shaikh
 - 405-334-5720
- Nancy Trautmann, Cornell University
 - (607) 255-9257
 - [[HYPERLINK "mailto:nmt2@cornell.edu"](mailto:nmt2@cornell.edu)]
 - Technology: bioremediation of contaminated soils
- Jay H. Lehr; AR Environmental Services Incorporated, Senior Scientist
 - (312) 377-4000
 - [[HYPERLINK "mailto:jlehr@heartland.org"](mailto:jlehr@heartland.org)]
 - [[HYPERLINK "http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471455997.html"](http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471455997.html) \t "_blank"]
- Gregory Gervais; CERCLA—OSRTI/TIFSD
 - 703-603-0690
 - [[HYPERLINK "mailto:Gervais.Gregory@epa.gov"](mailto:Gervais.Gregory@epa.gov)]
- Luciana DiGhionno; DOT,
 - (202) 366-8553
 - [[HYPERLINK "mailto:luciana.dighionno@dot.gov"](mailto:luciana.dighionno@dot.gov)]
- NFPA Treatment Work Group
 - Ask Ken for specific individuals/contact information
- David Heaven; Technical Advisor, Hazardous Devices Program Support, Inc
 - (256) 656-2283 **OR** (256) 705-3579
 - [[HYPERLINK "mailto:david.heaven@hdps-hsv.com"](mailto:david.heaven@hdps-hsv.com)]

- Detective Lt. Kevin Power; Nassau County Arson/Bomb Squad
 - (516) 573-8850
- Keith Clift; Senior Physical Scientist, Defense Ammunition Center
 - (918) 420-8719
- Dr. Solim Kwak; Former Senior Science Advisor, Defense Ammunition Center
 - (918) 420-8618
- Ricky Stauber; UXO Operations Manager
 - (301) 653-0996
- Randy Kramer; Indian Head Explosive Ordnance Disposal Technology Division
 -
- Rick Stauber; Master EOD Technician
 - (706) 316-3525
 - [HYPERLINK "mailto:Eod1952@verizon.net"]